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# ***Automated Coordinated Mission Planning Across Constellations***

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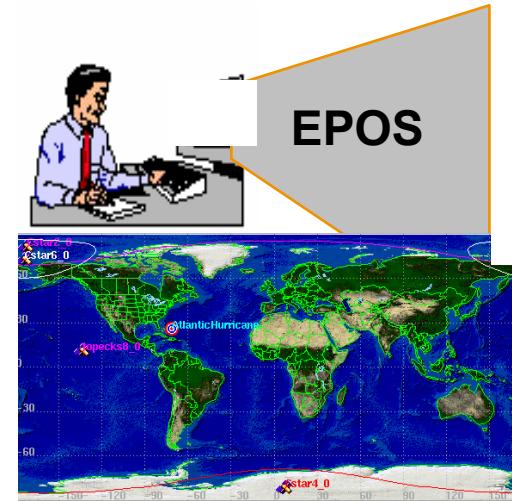


- **Summary**
- **Concept of operations**
- **Evaluation of timeliness**
- **Current version of EPOS**
- **Situation awareness/assessment: cloud mask generation**
- **Benefits from dynamic TES tasking – preliminary results**

# *Summary from Previous Years*

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- Developed technologies for an automated mission manager that:
  - Efficiently utilizes a complementary and cooperative suite of heterogeneous Earth-observing space-based sensor platforms
  - Responds to significant events, providing enhanced understanding of ephemeral Earth phenomena that impact human life and property, e.g., hurricanes, volcanoes, biomass burning (e.g., forest fires)
  - Provides for long-term data gathering



- Implemented and demonstrated these technologies in EPOS: Earth Phenomena Observing System
  - EPOS 1.0 optimizes with potentially maneuvering satellites, few targets
  - EPOS 2.0 optimizes with many (tested with up to 105) coasting satellites, many targets (tested with up to 1400+)

# ***Summary of Current Year***

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- **Increasing the TRL of EPOS from current TRL 3**
  - Modify EPOS 2.0 to model existing satellites (and satellites to be launched in the near future)
    - ◆ An emphasis on the Morning and Afternoon Constellations
    - ◆ Special attention to MODIS on Terra and Aqua, as well as TES on Aura
- **Developing new higher fidelity system models, e.g.,**
  - Satellite
  - Sensor
  - Communication
  - Data products
- **Developing new operational concepts made possible by enhancing EPOS' mission manager**

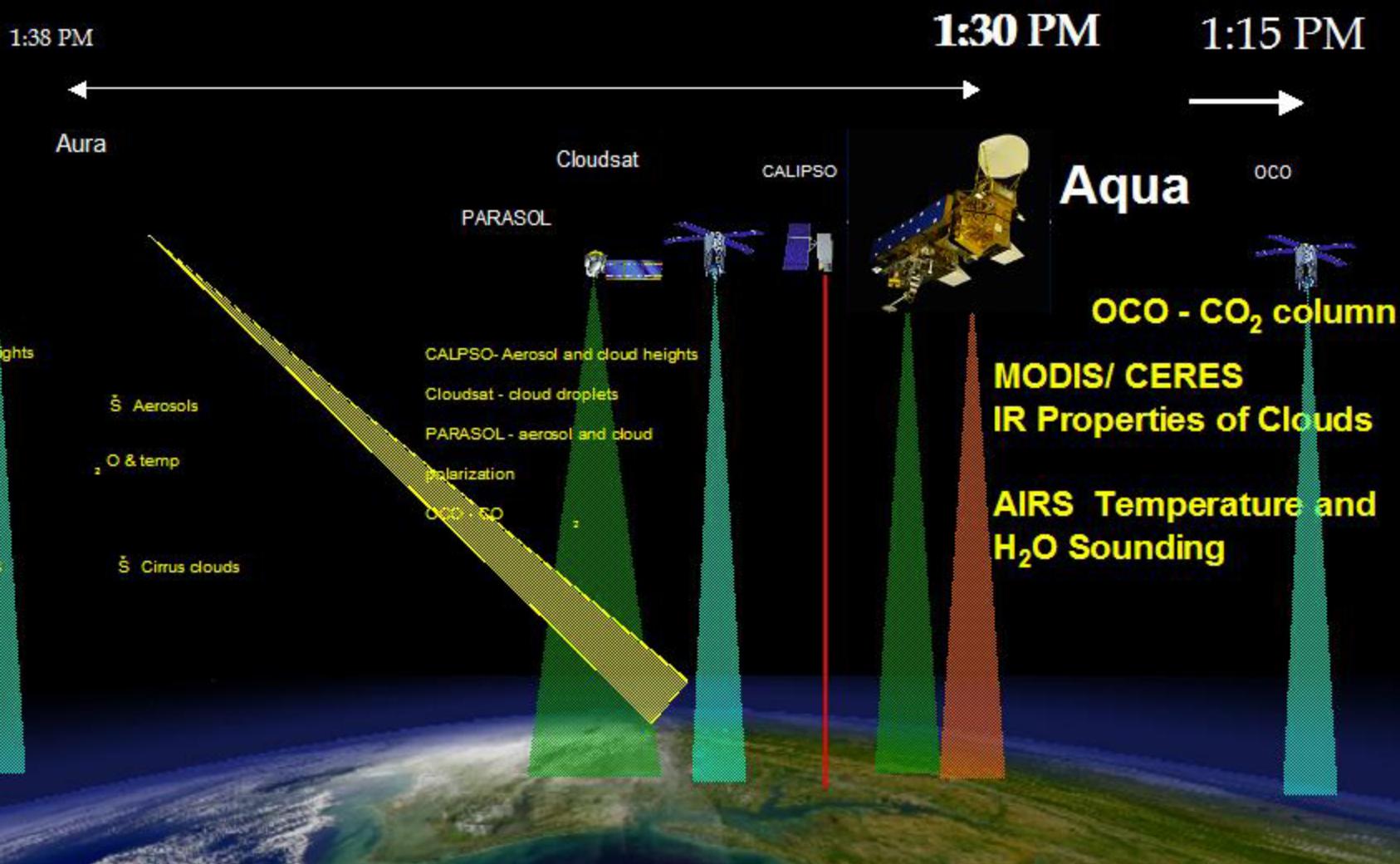
**MODIS** (or Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These data will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS is playing a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

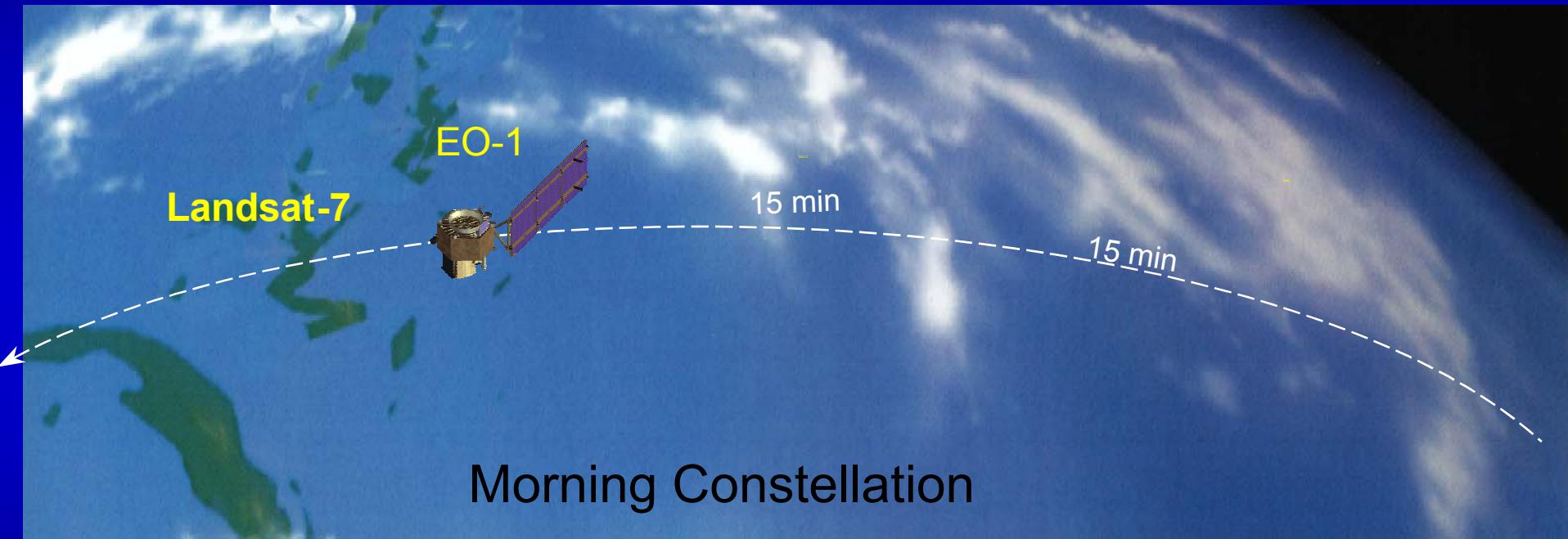
**TES is a high-resolution infrared-imaging Fourier transform spectrometer with spectral coverage of 3.2 to 15.4  $\mu\text{m}$  at a spectral resolution of 0.025  $\text{cm}^{-1}$ , thus offering line-width-limited discrimination of essentially all radiative active molecular species in the Earth's lower atmosphere. TES has the capability to make both limb and nadir observations. In the limb mode, TES has a height resolution of 2.3 km, with coverage from 0 to 34 km. In the downlooking modes, TES has a spatial resolution of  $0.53 \times 5.3$  km with a swath of  $5.3 \times 8.5$  km. TES is a pointable instrument and can access any target within  $45^\circ$  of the local vertical, or produce regional transects up to 885-km length without any gaps in coverage. TES employs both the natural thermal emission of the surface and atmosphere and reflected sunlight, thereby providing day-night coverage anywhere on the globe. Observations from TES will further understanding of long-term variations in the quantity, distribution, and mixing of minor gases in the troposphere, including sources, sinks, troposphere-stratosphere exchange, and the resulting effects on climate and the biosphere. TES will provide global maps of tropospheric ozone and its photochemical precursors.**

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# The Aqua/Aura Afternoon Constellation

## The “A Train”





# *Concept of Operations Overview*

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- A significant trend in the design of systems of Earth observing satellites is the notion of multiple spacecraft working collaboratively
- One class of collaborative satellites is a confederation, a group of heterogeneous, non-interacting satellites observing similar phenomena in near real-time
  - ◆ Raymond, C. A., J. O. Bristow, and M. R. Schoeberl, Needs for an Intelligent Distributed Spacecraft Infrastructure, Earth Science Vision Session, IGARSS 2002, Toronto, Canada
- ↑ Goal: enhance the capability to improve the science data gathering of a confederation of satellites by changing the non-interacting nature of confederations to interacting, by explicitly using the data gathered from one or more satellites to influence the data gathered from others

# *Concept of Operations Focus*

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- **Focus on real-time cueing**
- **Real-time cueing refers to taking measurements made by one or more sensors on one satellite and using them to cue the tasking of another satellite's sensors**
- **Data from a cueing satellite will provide the situation awareness and assessment for use in dynamic tasking of one or more sensors on later\* satellites**

\*Later is measured by the times satellites can observe a given location on Earth.

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# *Concept of Operations – Initial Step*

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- Both Aqua and Terra have a MODIS instrument
  - They have no on-board processing capability to generate a MODIS cloud mask
  - MODIS data is broadcast on X-band and is available in near real time
- Initial capability: use MODIS cloud mask data as input in the tasking of Aura/TES, which cannot see through clouds
- TES observation targets include volcanoes

# *Concept of Operations – Evaluation of Timeliness*

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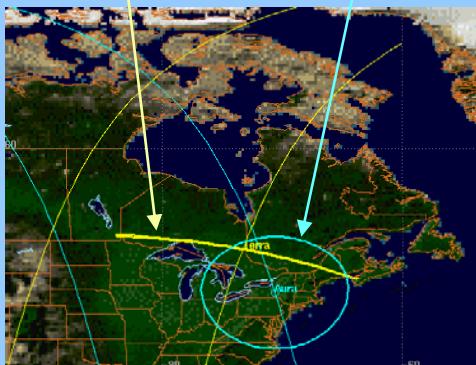
- Initial feasibility check
- Single volcano – Kilauea
- 1400+ volcanoes listed on the Smithsonian Institution Global Volcanism Program web site
  - [http://www.volcano.si.edu/gvp/volcano/vbd\\_geog.htm](http://www.volcano.si.edu/gvp/volcano/vbd_geog.htm)

# **Initial Feasibility Check of Terra/MODIS to TES Cueing**

- Terra/MODIS swath at three times
- Region viewable by TES (pointable with a slew limit of 45 degrees from nadir) at three later times
- Not enough lead time to use same revolution Aqua/MODIS data

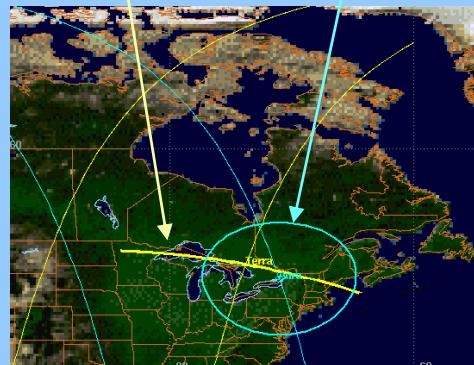
Swath of MODIS sensor on Terra at time 16:27:10 UTC

Accessible area for an observation by TES on Aura at time 18:07:00 UTC



Swath of MODIS sensor on Terra at time 16:27:40 UTC

Accessible area for an observation by TES on Aura at time 18:07:30 UTC



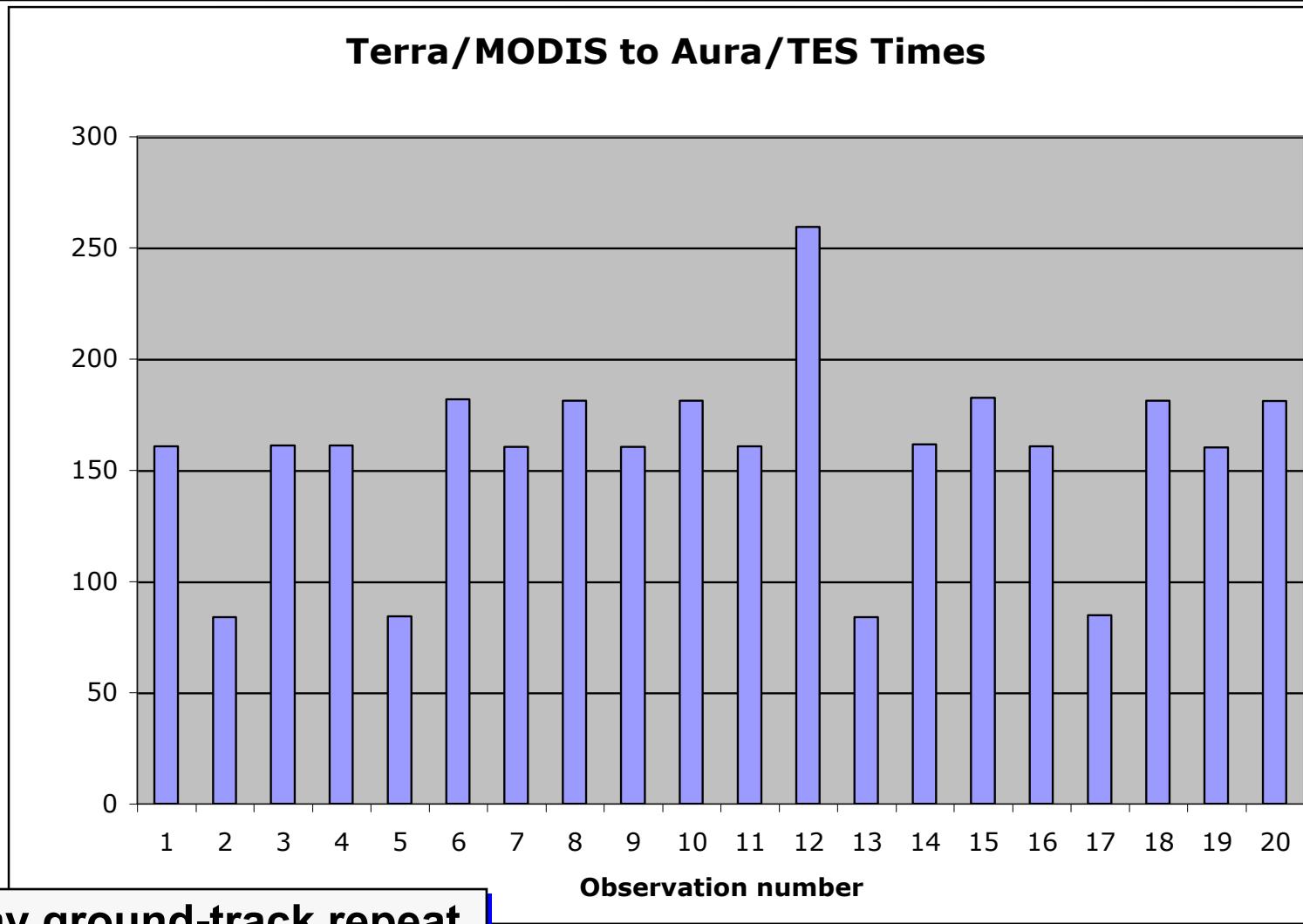
November 5, 2002

Swath of MODIS sensor on Terra at time 16:28:10 UTC

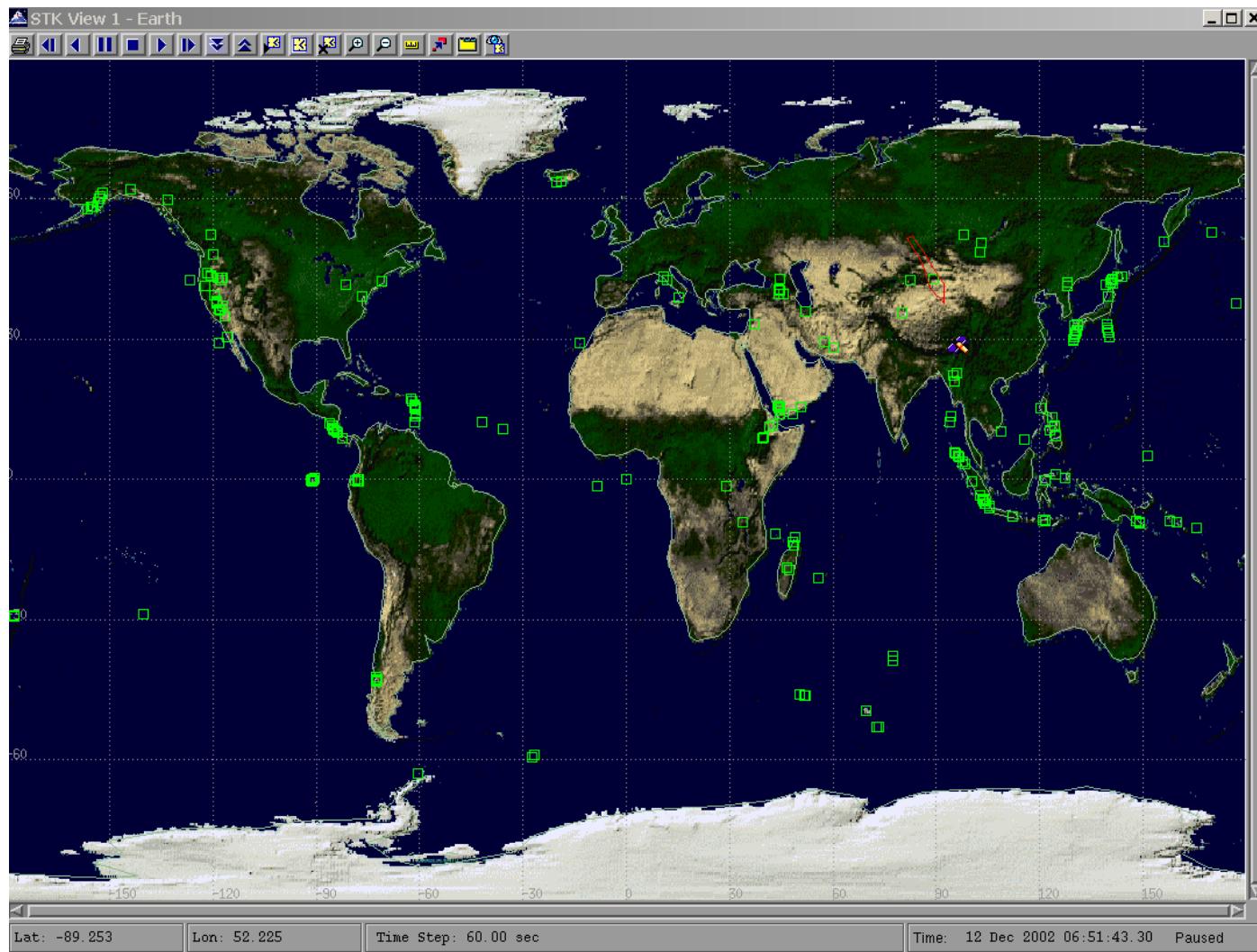
Accessible area for an observation by TES on Aura at time 18:08:00 UTC



# *Terra/MODIS Data is Timely for TES Tasking to View Kilauea in Hawaii*



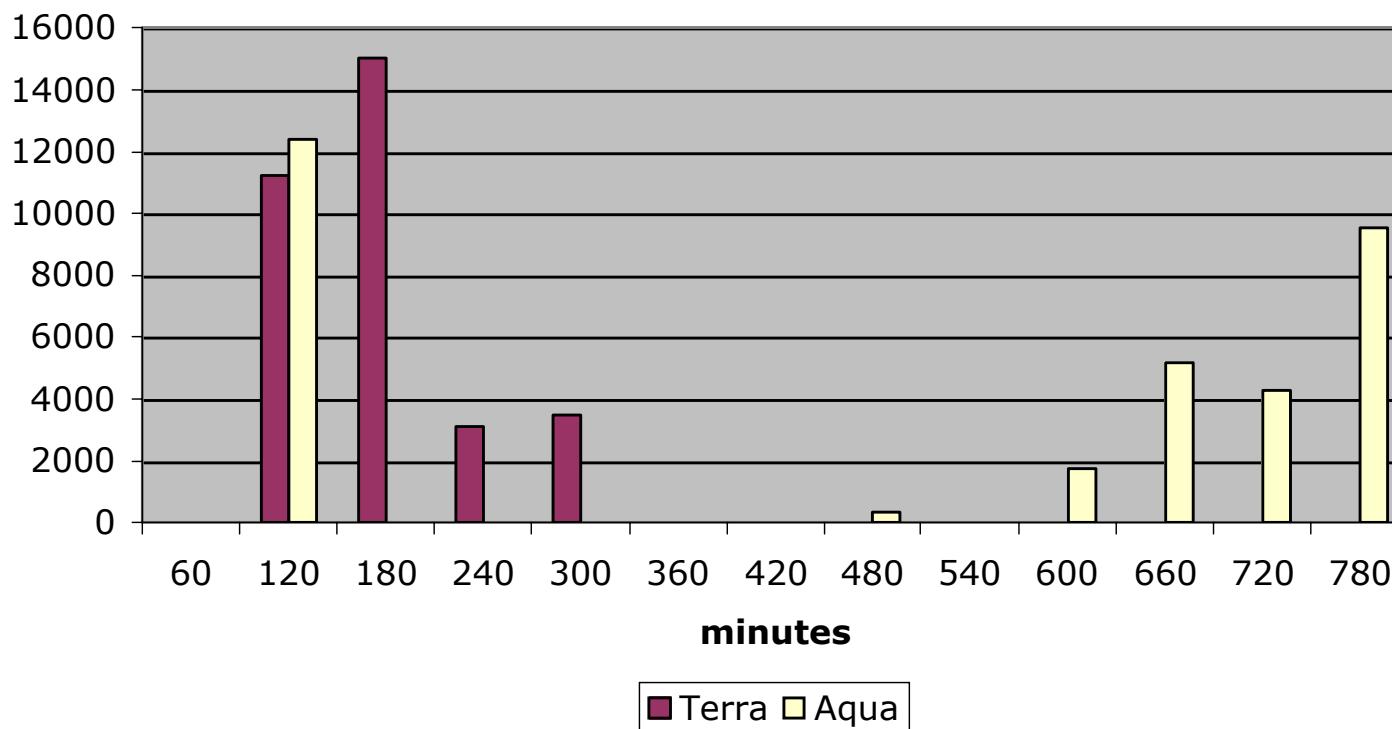
# 1400+ Volcanoes\*



\*Smithsonian Institution Global Volcanism Program  
[http://www.volcano.si.edu/gvp/volcano/vbd\\_geog.htm](http://www.volcano.si.edu/gvp/volcano/vbd_geog.htm)

# ***MODIS Data is Timely for TES Tasking to View 1400+ Volcanoes***

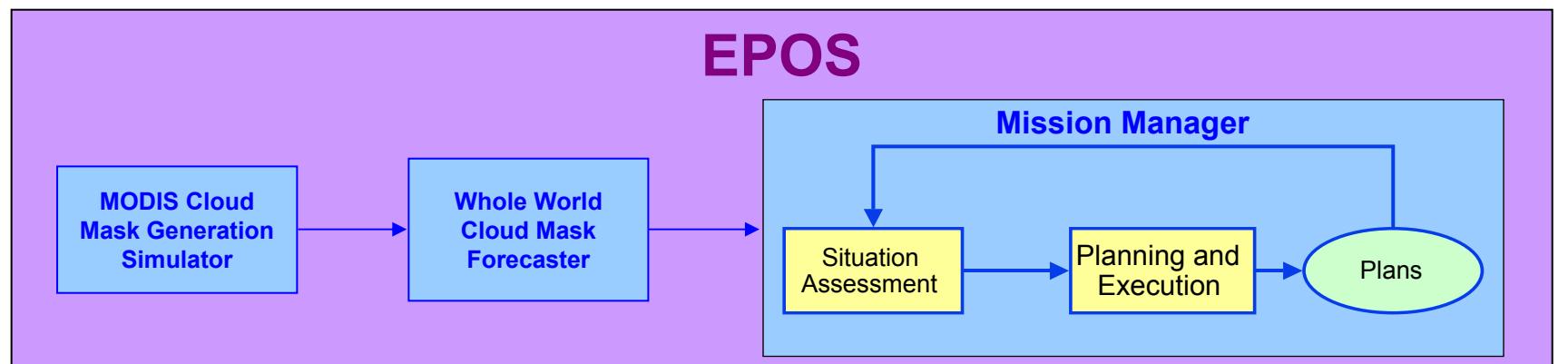
**Minimum Time Between MODIS and Possible TES  
Observations (> 60 minutes)**



**1400+ volcanoes, data from 16 day  
ground-track repeat cycle**

# *Current Version of EPOS: Earth Phenomena Observing System*

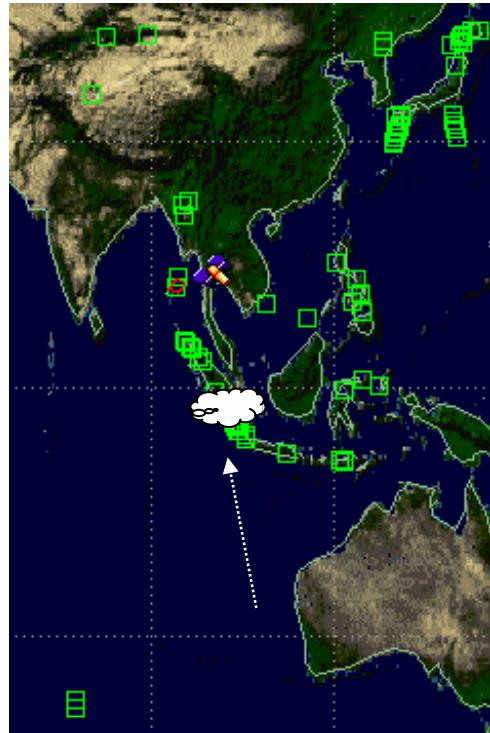
- **MODIS Cloud Mask Generation Simulator**
  - Use April 15-18, 2003 data ordered from EOS Data Gateway
    - ◆ <http://redhook.gsfc.nasa.gov/~imswww/pub/imswelcome/>
  - Plans are to include other sensor sources, e.g., GOES
- **Whole World Cloud Mask Forecaster**
  - Initial version uses the latest data available
- **Situation Assessment**
  - Handles a time stream of cloud mask data files
- **Planning and Execution**
  - Utilizes cloud mask information in optimization
- **Plans currently sent to STK for visualization**



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# *EPOS Used to Analyze Benefits from Dynamic TES Tasking: Preliminary Results*

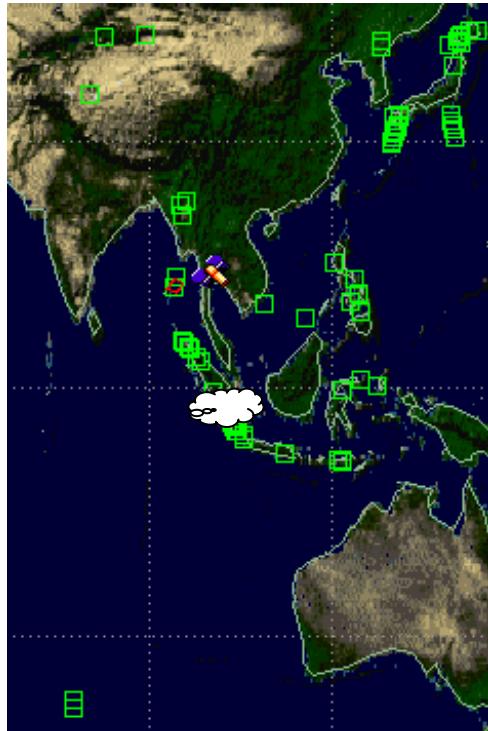
# Target Selection Planned Without Using Cloud Mask Data



50T: 22 00:22:00 Targ:143(	Dempo) ( -8.030, 112.130) Val: 30.00
50T: 23 00:23:00 Targ:143(	Dempo) ( -8.030, 112.130) Val: 30.00
50T: 24 00:24:00 Targ:151(	Hulubelu) ( -5.350, 104.600) Val: 40.00
50T: 25 00:25:00 Targ:141(	Kaba) ( -3.520, 102.620) Val: 40.00
50T: 26 00:26:00 Targ:141(	Kaba) ( -3.520, 102.620) Val: 40.00
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50T: 29 00:29:00 Targ:141(	Kaba) ( -3.520, 102.620) Val: 40.00
50T: 30 00:30:00 Targ:150(Sekincau_Beliran) (	-5.120, 104.320) Val: 40.00
50T: 31 00:31:00 Targ:145(	Patah) ( -4.270, 103.300) Val: 40.00
50T: 32 00:32:00 Targ:151(	Hulubelu) ( -5.350, 104.600) Val: 40.00
50T: 33 00:33:00 Targ:126(	Turfan) ( 42.900, 89.250) Val: 30.00
50T: 34 00:34:00 Targ:126(	Turfan) ( 42.900, 89.250) Val: 30.00
50T: 35 00:35:00 Targ:130(	Popa) ( 20.870, 95.230) Val: 30.00
50T: 36 00:36:00 Targ:126(	Turfan) ( 42.900, 89.250) Val: 30.00
50T: 37 00:37:00 Targ:126(	Turfan) ( 42.900, 89.250) Val: 30.00
50T: 38 00:38:00 Targ:123(Kunlun_Volc_Grou) (	35.520, 80.200) Val: 30.00
50T: 39 00:39:00 Targ:123(Kunlun_Volc_Grou) (	35.520, 80.200) Val: 30.00
50T: 40 00:40:00 Targ:125(Tianshan_Volc_Gr) (	42.500, 82.500) Val: 30.00
50T: 41 00:41:00 Targ:125(Tianshan_Volc_Gr) (	42.500, 82.500) Val: 30.00
50T: 42 00:42:00 Targ:137(	Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00
50T: 43 00:43:00 Targ:137(	Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00
50T: 44 00:44:00 Targ:137(	Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00
50T: 45 00:45:00 Targ:137(	Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00
50T: 46 00:46:00 Targ:137(	Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00
50T: 47 00:47:00 Targ:137(	Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00

Targets in red oval are under cloud cover

# *Realized Value from Targets Actually Observed*



50T:	22 00:22:00	Targ:143(	Dempo) ( -8.030, 112.130) Val: 30.00
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50T:	47 00:47:00	Targ:137(Ulug-Arginsky) ( 52.330, 98.000) Val: 30.00	

Targets in red cannot be observed due to cloud cover

# *Target Observations Planned Using Cloud Mask Data*



50T:	22 00:22:00	Targ:143(	Dempo) ( -8.030, 112.130)	Val: 30.00
50T:	23 00:23:00	Targ:143(	Dempo) ( -8.030, 112.130)	Val: 30.00
50T:	24 00:24:00	Targ:143(	Dempo) ( -8.030, 112.130)	Val: 40.00
50T:	25 00:25:00	Targ:152(	Krakatau) ( -6.102, 105.423)	Val: 40.00
50T:	26 00:26:00	Targ:152(	Krakatau) ( -6.102, 105.423)	Val: 40.00
50T:	27 00:27:00	Targ:138(	Sinabung) ( 3.170, 98.392)	Val: 40.00
50T:	28 00:28:00	Targ:132(	Seulawah_Agam) ( 5.448, 95.658)	Val: 30.00
50T:	29 00:29:00	Targ:136(	Kembar) ( 3.850, 97.664)	Val: 40.00
50T:	30 00:30:00	Targ:132(	Seulawah_Agam) ( 5.448, 95.658)	Val: 40.00
50T:	31 00:31:00	Targ:127(	Barren_Island) ( 12.292, 93.875)	Val: 30.00
50T:	32 00:32:00	Targ:129(	Lower Chindwin) ( 22.280, 95.100)	Val: 40.00
50T:	33 00:33:00	Targ:133(	Singu_Plateau) ( 22.700, 95.980)	Val: 30.00
50T:	34 00:34:00	Targ:126(	Turfan) ( 42.900, 89.250)	Val: 30.00
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50T:	47 00:47:00	Targ:137(	Ulug-Arginsky) ( 52.330, 98.000)	Val: 30.00
50T:	48 00:48:00	Targ:137(	Ulug-Arginsky) ( 52.330, 98.000)	Val: 30.00

Here the Cloud Mask data is used in EPOS Situation Assessment and Planning  
The result is that the non-obscured targets in grey are selected in the plan

# Planning which Utilizes Cloud Mask Data Results in Added Realized Science Value

No Value for Observations through Clouds

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18 Observations

Optimized Planner Selects Viewable Targets

50T:	22 00:22:00 Targ:143(	Dempo) ( -8.030, 112.130)
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27 Observations

# *Increasing the Fidelity of System Models*

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- In order to increase the TRL of EPOS above 3, we have started to perform experiments with full-scale data sets
- To continue to increase the TRL to 4 and above, will need higher fidelity system models
- Have developed initial models for these system components
  - Satellite
  - Sensor
  - Communication
  - Data products
- Will also provide context for the development of additional operational concepts

# Example: Sensor Model

Sensor													
	ID	Name	Description	FOV		Replen Capacity		Data Bands		Modes			
Example Record	Sensor_1	ASTER	Adv_SP_ther Radiom	Type	Data	Capacity	Replenish Amount	Num Bands	Band list	TypeList	Parameters	Depletion	Movement Cost
				Conical	CON_FOV1	100	20	3	Bands_01	Calibration	Cal_01	1	0.01
										Normal	Norm_01		
										Taskable	Task_01		

Conical Field of View									
	FOV (deg)		max slew (deg)		slew rates (deg/sec)		other param		
ID	x	y	x	y	x	y	x	y	
Example Record	CON_FOV1	4	2	30	3	1.0	1.0	1.0	1.0

Scanning Field of View							
	Rectang (km)		scan rate		other param		
ID	x	y	x	y	x	y	
Example Record	SCN_FOV1	4	2	30	3	1.0	1.0

Data Bands			
ID	# Bands	Band #	Data Type
Example Record	Bands_01	3	CO2
		1	
		2	Temp
		3	Humid

Sensor Modes			
ID	Abbrev	% in mode	Param 2
Example Record	SNS_MODES1	Cal_01	20

# ***Summary***

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- Developed a new concept of operations for cooperative operation of sensors on different satellite
- Performed initial evaluation and analysis of this concept of operations
- Extending and enhancing EPOS as it moves from TRL 3 to TRL 4
- Increasing the fidelity of the system model
- Exploring additional concepts of operations that will be feasible using EPOS technology